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Accelerating Groundwater and Energy Use for Agricultural Growth in Odisha: Technological and Policy Issues§

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Abstract

The groundwater resources in Odisha, one of the eastern states of India, suffer from the dual problems of under-development and under-utilization of available irrigation potential. The present paper has unravelled the pattern of groundwater development and its utilization, has evaluated the prospects of energy regulation and has suggested technological and policy options for sustainable management of groundwater resources. About a quarter of the groundwater structures in Odisha are non-functional and these may be targeted on priority to improve the irrigation infrastructure. The cost of groundwater extraction in the hard rock region is 2-3 times more than in the coastal/alluvial region, depending on the type of wells and energy sources. The assured and quality electricity supply can accelerate groundwater utilization. A part of investment for such infrastructure can accrue from the reducing existing subsidy on power. The groundwater extraction cost with higher electricity tariff after removal of subsidy is lower than that incurred using diesel-operated pumps, even at the subsidized diesel price. There is ample opportunity to harness the potential of groundwater resources through suitable technological interventions and energy regulations for accelerated agricultural growth in Odisha.

Key words: Groundwater utilization, energy cost, agricultural performance, Odisha

JEL Classification: Q16, Q40

Introduction

Groundwater irrigation has played a central role in enhancing food production in India. Agriculture consumes 92 per cent of the annual groundwater draft (CWC, 2010); and therefore, management of this precious resource holds the key to agricultural growth. India's water policy stresses on optimization of groundwater-use in a way that its draft does not exceed its recharge potential (GoI, 2002a). However, groundwater development in India is not in congruence with the policy of sustainable and equitable exploitation of groundwater (Jeet, 2005). While it is over-exploited in the north-western states, it remains poorly-developed and under-utilized in the eastern states on account of several economic and non-economic reasons (Srivastava *et al*., 2012). The eastern region has 130 billion cubic metre (BCM) of annual replenishable groundwater, yet only 27 per cent of it has been developed (Srivastava *et al*., 2014). Thus, there is ample scope to harness groundwater potential in this region for enhancing agricultural growth and benefits of the farmers.

In Odisha, one of the eastern states of India, only 26 per cent of 16.69 BCM net annual replenishable groundwater is extracted, mainly for irrigation purposes (79.6%) (GoO, 2011a). Its level of utilization also

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varies considerably across hydro-geological settings (Srivastava *et al*., 2013). This warrants a separate investigation on groundwater development and its utilization in different hydro-geological settings.

Further, regulation of energy-use is a powerful tool in management of groundwater resources (Scot *et al*., 2003; Kumar *el al*., 2005) and understanding of energy-use dynamics for groundwater irrigation is crucial to accelerate groundwater development. The present paper unravels the pattern of groundwater development and its utilization, evaluates prospects of energy regulation and suggests technological and policy options for sustainable management of groundwater resources in Odisha.

Data and Methodology

The paper has used secondary data collected from published sources such as *Groundwater Exploration in Orissa* (GoI, 2002b), *Odisha Agriculture Statistics* (GoO, 2008), *Groundwater Resources in Odisha* (GoO, 2011a), and *4th Minor Irrigation (MI) Census* (GoO, 2011b).Since groundwater utilization is influenced by the hydro-geological conditions, analysis was done for hard rock and alluvial regions separately. The relationship between groundwater development and agricultural income was studied using log-log function and the equation was estimated using ordinary least square (OLS) technique.

$$\log (Y) = c + b^* \log (X) + e \qquad \ldots (1)$$

where,

Y = Net district domestic product from agriculture (₹/ha)

c = Intercept

b = Regression coefficient

X = Groundwater development (%), and

e = Error-term.

The energy-use dynamics of groundwater irrigation was studied in terms of cost of groundwater extraction with alternative energy sources, viz. diesel and electricity, and by type of groundwater structures, viz. shallow tubewells, deep tubewells and dugwells. An exercise was also undertaken to evaluate the implications of removing the subsidy on electricity for groundwater extraction. Steps involved in the estimation of cost of per cubic metre groundwater extraction are as follows:

Estimation of Average Horse Power of Pumps and Energy Equivalents

The average horse power (Hp) was estimated as the weighted average[1] using information from 4th *MI Census*. This was converted into energy equivalent (kilowatt) by multiplying it with a factor of 0.746. For the dugwells operated using 'man/animal' energy, 0.28 kW [(average of 0.06 kW (male), 0.048 kW (female) and 0.746 kW (drought animal)] was used as the energy equivalent factor (Srivastava, 2002).

Estimation of Total Head

The total head was estimated using Equation (2):

$$\text{Total head (m)} = \text{Water table (m)} + \text{draw down (m)} + \text{friction loss} \qquad \ldots (2)$$

Ten per cent of the water table and draw down was taken as friction loss.

Estimation of Groundwater Draft

The groundwater draft (L/sec) was estimated using Equation (3):

$$\text{Groundwater draft (L/sec)} = \frac{\text{HP} \times 75 \times \text{Pump efficiency}}{\text{Total head (m)}} \qquad \ldots (3)$$

The pumpset efficiency was assumed to be 40 per cent. The annual groundwater extraction was estimated using information such as number of pumping days in monsoon and non-monsoon seasons and the average pumping hours per day. The number of pumping days in monsoon and non-monsoon seasons was taken as 50 and 120, respectively (GoO, 2011a). The average pumping hours per day for different groundwater structures were calculated as the weighted average using information from 4th *MI Census*.

[1]*MI Census* publishes distribution of groundwater structures across different categories of horse power of pumps. The number of groundwater structures was taken as the weight to calculate the average Hp (weighted average) of the pumps used in groundwater extraction.

Estimation of Energy Cost on Groundwater Extraction

For diesel-operated pumps, discussions with farmers revealed that 1 Hp pumpset consumes about 0.25 litre of diesel per hour. The energy was expressed in monetary terms (₹/cu.m) by multiplying with diesel price of ₹ 45 per litre and electricity price of ₹ 1.10 per kW. The resultant was divided with the groundwater draft to calculate the energy cost per unit groundwater extraction

Estimation of Total Annual Amortized Cost of Groundwater Structure

The amortized cost of digging and pumpset cost was estimated as per following formula (4):

$$A = \frac{CB * (1+i)^n * i}{(1+i)^n - 1} \qquad \dots(4)$$

where,

A = Amortized cost of digging/pumpset (₹)

CB = Compound cost of digging/pumpset (₹)

i = Interest rate (6%), and

n = Life of groundwater structure.

In the hard rock region, average life of groundwater structure was assumed to be 15 years, while in the alluvial/coastal region, it was assumed as 20 years. The average life of a pumpset was assumed to be 10 years. The annual maintenance cost was assumed as 5 per cent of the pumpset cost for diesel-operated pumps and 1 per cent for the electricity-operated pumps. The total annual amortized cost comprised amortized cost of digging, pumpset and maintenance.

Estimation of Total Cost on Groundwater Extraction

The total cost of groundwater extraction (₹/cu.m) comprised the total amortized cost associated with the groundwater structures and the cost of energy.

Results and Discussion

Agricultural Sector of Odisha

Odisha occupies 4.74 per cent of the country's geographical area and 3-4 per cent of the total agricultural and irrigated lands (Table 1). The agriculture and allied sectors contribute about 30 per cent to the state's gross domestic product (GDP) and provide livelihood to about 60 per cent of the workforce

Table 1. Selected indicators of development of agriculture in Odisha, TE 2008-09

Particulars	Odisha			India
	Hard-rock	Alluvial	Total	
Geographical area (Mha)	13.48	2.09	15.57	328.73
Net sown area (Mha)	4.57	1.08	5.65	140.76
	(0.01)	(-0.50)	(-0.50)	(0.20)
Gross sown area(Mha)	7.17	1.90	9.07	194.25
	(2.09)	(1.50)	(1.57)	(0.86)
Normal rainfall (mm)	1437	1498	1451	1190
Net irrigated area (Mha)	1.48	0.57	2.05	63.00
	(5.67)	(4.76)	(4.36)	(2.06)
Gross irrigated area (Mha)	2.26	0.98	3.24	87.70
	(6.84)	(7.86)	(6.49)	(2.27)
Groundwater development (%)	20.57	42.66	26.14	58
Fertilizer consumption (kg/ha)	46	75	54	118
	(4.65)	(5.71)	(4.88)	(4.47)
Share of agriculture in total electricity consumption (%)	-	-	1.30	20.97
Cropping intensity (%)	157	176	161	138
Irrigation coverage (%)	31.49	51.76	35.73	45.15

Note: Figures within the parentheses are compound growth rate (CGR) during 2000-01 to 2008-09

Table 2. Yield performance of major crops in Odisha *vis-à-vis* India

Crops	Yield in TE 2008-09 (kg/ha)		Long-run growth rate (1950-2008)		Short-run growth rate (2000-2008)	
	Odisha	India	Odisha	India	Odisha	India
Rice	1610	2173	1.65	2.01	5.68	1.92
Pulses	466	631	-0.36	0.46	3.79	1.70
Foodgrains	1269	1838	1.18	2.31	4.85	1.83
Oilseeds	790	1019	1.41	1.49	5.45	3.48

(GoO, 2010). Odisha's agriculture is primarily rainfed, the irrigated area being only 35.62 per cent, and is dominated by paddy-fallow/pulses copping pattern. Paddy occupied 67 per cent of total *kharif* area, and pulses occupied 50 per cent of total *rabi* area in the triennium ending (TE) 2008-09. The cropping intensity in the state is 22 percentage points higher than the national average. However, the yield of major crops is far less than the national average(Table 2).

The low level of input-use in agriculture and low irrigation-coverage are the major reasons for the lower crop yield in the state. The per hectare fertilizer consumption in the state (54 kg/ha) is less than half of the national average. Although the average rainfall is higher in Odisha (1451 mm) than the national average (1190 mm), irrigation coverage is only 35.6 per cent as compared to the national average of 45.1 per cent. The irrigation coverage in Odisha is at par with Rajasthan (35%), which receives only 200-600 mm of annual rainfall (GoI, 2011). This reflects the poor development of water storage and irrigation infrastructure, leading to flood-like situation during *kharif* season, followed by moisture stress during *rabi* season. The development of groundwater resources (share of draft in total groundwater availability) is only 26.1 per cent with wide inter-regional variability. The low level of groundwater-use for irrigation is also reflected from the fact that the agricultural sector consumes only 1.3 per cent of the total electricity consumption in the state as compared to the national average of 21 per cent.

Across hydro-geological regions, the level of groundwater development, fertilizer consumption, irrigation coverage and cropping intensity is much higher in the alluvial region (Table1). The higher level of input utilization, irrigation development and vast tracts of plain and fertile land (Swain *et al*., 2009) lead to better performance in this region. Overall, the agricultural sector of Odisha can be characterized as low input-low return with regional inequality. However, in recent years, Odisha's agriculture has started catching up with better performing regions of the country. This is reflected in significantly higher growth in irrigated area, fertilizer consumption, and yield of major crops in the state than in the nation during the past decade (Tables 1 and 2). The sustainable development of under-utilized groundwater resources will provide a fillip to the agricultural growth and development in the state.

Groundwater Irrigation-Agricultural Income Linkage

Groundwater is used to irrigate only 6.14 per cent of the gross irrigated area (GIA), but it has a positive impact on agricultural income in the state. The elasticity of agricultural income with respect to groundwater development is positive (0.598) and significant at 1 per cent level (Table 3). This indicates that improvement in groundwater development will increase the agricultural income in the state. It has been estimated that 47.75 per cent of the total ultimate irrigation potential[2] (8.8 Mha) can be developed using groundwater (CWC, 2010). But, till now only 13.0 per cent (5.5 lakh ha) of the ultimate irrigation potential has been created using groundwater resources (GoO, 2011b). Thus, there is enough scope for improving agricultural income through sustainable groundwater development.

[2]Ultimate irrigation potential (UIP) is the gross irrigated area that theoretically could be irrigated if all available land and water resources were used for irrigation

Table 3. Regression analysis of agricultural income and groundwater development

Dependent variable: Per ha net district domestic product from agriculture (₹/ha) in logarithmic form

Particulars	Coefficient
Constant	8.569*
	(0.631)
Groundwater development (log)	0.598*
	(0.199)
R^2	0.244
No. of observations	30

Notes: *significant at 1 per cent degree of significance

Figures within the parentheses are standard errors of estimated coefficients

Regional Pattern in Groundwater Development and its Utilization

The under-development of groundwater resources is accompanied by wide regional variability due to several hydro-geological, climatic, agrarian and socio-economic constraints. Groundwater development varies from 8.76 per cent in Malkangiri district to 55.49 per cent in Bhadrak district of Odisha. A quartile based classification reveals that in 75 per cent (3rd quartile) of the total community development blocks (314), groundwater development is less than 34 per cent and most of the blocks with better groundwater development lie in the alluvial/coastal tract (Figure 1). The average groundwater development in this tract is 42.66 per cent varying from 17.77 per cent in the Puri district to 55.49 per cent in the Bhadrak district (Table 4). The favourable aquifer properties (high discharge, low draw-down and high water level) in the coastal region also result in comparatively low energy requirement to lift groundwater. However, this region is hydrologically sensitive to sea-water intrusion and 42 coastal blocks are already partially or fully affected by the salinity problem. Hence, safe pumping options should be followed in order to use the groundwater on a sustainable basis in this region. Based on Ghyben-Herzbeg approach and basic groundwater flow concept, it has been suggested that restriction of pumping depth within 6 to 20 metres (depending upon the distance from coast line) with maximum of two pumps (1-3 Hp) per square kilometre with 4-5 hours of continuous pumping will check the saline water ingression in 15-km strip from the coast (Sethi *et al.*, 2012).

On the other hand, in the hard rock region, groundwater development is only 20.57 per cent (varying from 8.76 % in Malkangiri district to 29.70 % in Khurda district). Poor groundwater development in this region is primarily due to low discharge, high draw-down, and heterogeneity in aquifer properties within the small areas. The average discharge, draw-down and water level (pre-monsoon) in the hard rock region have been estimated as 4.95 L/sec (0.08-65), 20.75 m (0.31-60.87) and 6.32m, respectively. The unfavourable hydro-geological conditions result in higher energy requirement to extract groundwater. The associated problems and therefore strategies for the sustainable groundwater development in different hydro-geological settings (hard rock/alluvial) would be different.

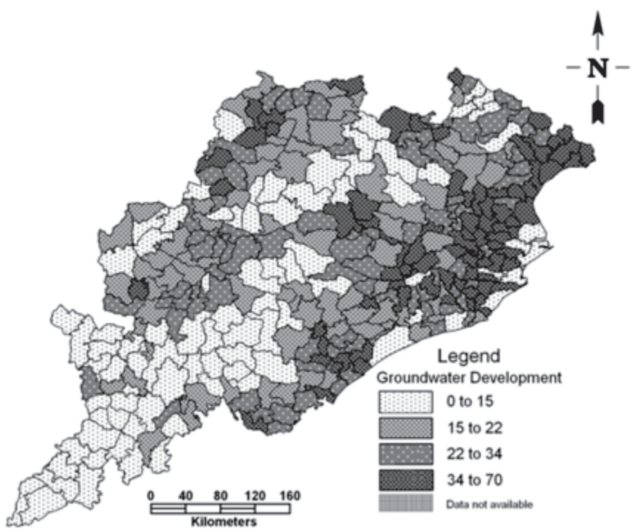

Figure 1. Classification of blocks based on groundwater development using quartile classes

The examination of structure and pattern of groundwater irrigation reveals dugwell as a dominant source (86 % of the total groundwater structures) of groundwater irrigation (Table 4). However, there are regional variations in the composition of groundwater structures and therefore, in the irrigation potential created through groundwater (IPCg) due to varying command area of different groundwater structures. In the hard rock region, dugwells are predominantly used (95.17% of total groundwater structures) for groundwater irrigation and constitutes 77.31 per cent of IPCg in the region. On the other hand, in the alluvial region, shallow tube-wells are the predominant groundwater structure constituting 63.15 per cent and

Table 4. Groundwater development status in Odisha

Particulars	Hard rock region	Alluvial region	Odisha
Net groundwater availability (BCM)	12.65	4.04	16.69
Groundwater draft (BCM)	2.69	1.67	4.36
Groundwater development (%)	20.57 (Min.: 8.76, Max.: 29.70)	42.66 (Min.: 17.77, Max.: 55.49)	26.12 (Min.: 8.76, Max.: 55.49)
Groundwater structures (No. '000)	396	76	472
Dugwells	382(95.17)#	24 (31.57)#	406 (86.02)#
Borwells/ deep tubewells	2(0.51)#	4 (5.26)#	6 (1.27)#
Shallow/Filter point wells	12(3.03)#	48 (63.15)#	60 (12.71)#
Irrigation potential created ('000 ha)	265.36	287.66	553.02
Dugwells	198.78 (77.31)#	18.07 (6.28)#	216.86 (39.21)#
Borewells/ deep tubewells	18.51(7.35)#	114.14 (39.68)#	132.65 (23.99)#
Shallow/Filter point wells	48.07 (18.74)#	155.44 (54.04)#	203.52 (36.80)#
Irrigation potential utilized ('000 ha)	106 (44.53)*	87.57 (30.44)*	197.29 (35.67)*
Dugwells	79.16(39.82)*	5.19 (28.72)*	84.35 (38.89)*
Borewells/deep tubewells	7.62(41.16)*	12.45 (10.91)*	20.07(15.13)*
Shallow/Filter point wells	22.94 (47.72)*	69.93 (44.99)*	92.87 (45.63)*
Proportion of non-working wells (%)	24.44	25.15	24.66
Dugwells	24.74	30.96	25.10
Borewells/deep tubewells	29.79	75.41	60.38
Shallow/Filter point wells	14.20	18.06	18.18
Average water level (m), 2009	6.32(Min.: -1.11, Max: 28.14)	5.03 (Min.: -0.5, Max.: 15.25)	6.02(Min.:-1.11, Max: 28.14)
Average discharge (L/sec)	4.95 (Min.: 0.08, Max.: 65)	43.29 (Min.: 0.50, Max.: 75.40)	13.90 (Min.: 0.08, Max.: 75.40)
Average draw-down (m)	20.75 (Min.: 0.31, Max.: 60.87)	10.99 (Min.: 2, Max.: 35)	18.48 (Min.: 0.31, Max.: 60.87)

Notes: # Figures within parentheses are the share of respective structures in total

* Figures within parentheses are per cent utilization of created irrigation potential

Data source: GoI (2002b), GoO (2011a; 2011b)

54.04 per cent of the total groundwater structures and the IPCg, respectively. As a result, the alluvial region comprises 52 per cent of the total IPCg in the state despite the fact it has only 19 per cent of agricultural land, 24 per cent of groundwater resources and 16 per cent of groundwater structures. The total IPCg in the state has increased from 3 lakh ha in 2000-01 (3rd *MI Census*) to 5.5 lakh ha in 2006-07 (4th *MI Census*) due to public as well as private investments in groundwater irrigation. The private investment accounts for about fifty percent of the IPCg in Odisha. Among the structures, 56.66 per cent, 49.44 per cent, and 12.65 per cent of shallow tubewells, dugwells, and deep tubewells have been constructed by the farmers using own funds, respectively.

However, the momentum of IPCg could not continue for the irrigation potential utilized (IPU) resulting in a decline in the per cent utilization (share of IPU in IPCg) of the created potential from 51.53 per cent in 2000-01 to 35.22 per cent in 2006-07. The poor utilization of the created irrigation potential leads to not only loss of financial resources but also the opportunity to improve agricultural productivity. Thus, groundwater sector in Odisha is suffering from the dual problems of under-development of groundwater resources and under-utilization of the created irrigation potential. Non-functioning of groundwater structures could be one of the reasons of under-utilization of created irrigation potential as about a quarter of groundwater structures are not in-use due to temporary (62.68%) or permanent (37.32%) reasons. These non-functional wells have led to the estimated loss of about 171.52 thousand ha (31% of IPCg) irrigation potential annually that may be targeted on priority for improving irrigation infrastructure in the state. Across the regions, utilization of the created irrigation potential is less in the alluvial/coastal (30.44%) region than in the hard rock region (44.53%) because of comparatively higher proportion of non-functional wells (particularly deep tubewells) in the former region. About 75 per cent of total deep tubewells in the alluvial region are non-functional and only 10.91 per cent of the total IPCg using deep tubewells is utilized. The performance of deep tubewells is comparatively better in the hard rock region where per cent utilization of IPCg using deep tubewellsis41.16 per cent. It is to be noted that 75 per cent of the total deep tubewells in the state are owned by the government and mass scale non-functionality of these structures sets a strong platform for transferring their ownership to the farmers. The transfer of operation and management of tubewells to *pani-panchayat* [water users association (WUA)]is being recognized steadily in India (Parthasarathy, 2000) and can be successfully adopted for the revival of deep tubewells in Odisha.

Further, different groundwater structures exhibit different reasons of non-functionality (temporary or permanent). About 33 per cent of the dugwells in the hard rock region are temporarily non-functional due to 'less well-discharge'. It is to be noted that more than 95 per cent of the groundwater structures have been constructed outside the command of any surface water bodies indicating the absence of any attempt to recharge the aquifers. This warrants is the urgent implementation of groundwater recharge activities to improve groundwater availability in the aquifers and therefore well-yield. Amongst various recharge techniques, percolation tanks are least expensive in terms of initial construction costs (Oaksford, 1985). Many such tanks already exist but a vast majority of these structures have silted up. Cleaning of the bed of these tanks will make them reusable. The government has initiated several artificial recharge schemes on pilot basis which need further strengthening with active people participation (CGWB:http://cgwb.gov.in/GroundWater/AR/Orissa.pdf).

In the case of shallow-wells and deep tubewells, 'mechanical breakdown' is the prime reason for their temporary non-functionality as 30 per cent and 39 per cent of these wells are non-functional due to it, respectively. These wells may be targeted and incentives may be provided to the farmers for repairing these wells. Among the permanent reasons, 'destruction' of wells is the single most important reason of non-functionality of all type of structures (51-71% of the permanent non-functional wells). Repairing and reinstallation of these structures will go a long way to improve the groundwater utilization and bring additional land under groundwater irrigation. 'Drying-up' of the wells is the second important reason for permanent non-functioning which needs to be addressed through suitable recharge planning.

Prospects of Energy Regulations for Sustainable Groundwater and Agricultural Development

Out of several direct and indirect demand-side management and supply-side augmentation approaches (Rosegrant, 1997; Kumar, 2003; Briscoe and Malik, 2006), regulation of energy supply and pricing is often suggested as an effective indirect approach for sustainable groundwater development (Malik, 2008). In Odisha, about 70 per cent of the total groundwater structures use 'manual/animal' power making it the predominant energy source for groundwater irrigation. However, there exists a regional variation in energy-use pattern for groundwater irrigation. In the hard rock region, about 80 per cent of the total groundwater structures use 'manual/animal' power for groundwater extraction. This energy source is primarily used for dugwells (82% of total dugwells) which is the most suitable groundwater structure in the hard rock region. The use of manually-operated dugwells leads to less draw-down and thus ensures reliable water supply than using diesel/electric pumps in these regions. On the other hand, in the alluvial region, 'diesel'is the major (48% of total functional groundwater structures used diesel) source of energy primarily due to predominance of diesel-operated shallow tubewells (59% of total shallow tubewells). The electric power is used by 30 per cent of the total groundwater structures in this region. Inspite of technological superiority and cheap operational and maintenance of electric pumps over diesel pumps, farmers are forced to use diesel pumps due to poor power infrastructure and unreliable electricity supply for irrigation purpose (Malik, 2008).

The implications of alternative commercial energy sources on irrigation cost were examined by estimating per cubic metre cost of groundwater extraction (₹/m^3) under varied hydro-geological settings (hard rock/ alluvial), groundwater structures (deep tubewell/ shallow tubewell/dugwell) and energy source (diesel/ electric). The groundwater extraction cost (₹/m^3) in the hard rock region is 2-3 times higher than in the alluvial region due to comparatively higher digging cost, higher head and less discharge in this region (Table 5). Energy-use is the crucial component of groundwater extraction cost. The groundwater extraction cost with diesel pump is 168 per cent (for dugwells) to 305 per cent (for deep tubewells and filter point wells) higher than with electric pump in the hard rock region and 289 per cent (for dugwells) to 530 per cent (for shallow tubewells) higher in the alluvial region. Further, the share of diesel in total irrigation cost is 41 per cent (for dugwells in the hard rock region) to 86 per cent (for shallow tubewells in the alluvial region), while the electricity constitutes only 5 per cent (for dugwells in the hard rock region) to 33 per cent (for shallow tubewells in the alluvial region) of the total irrigation cost. Therefore, the impact of unit increase in energy cost, a common phenomenon now-a-days, on total irrigation cost will be much less in electric-operated wells than in diesel pumps. However, in a situation which is plagued by poorly-developed power infrastructure, deficit and unreliable power supply, shifting from diesel to electric energy is the most challenging task.

Presently, for irrigation/agricultural sector, the electricity tariff in Odisha is 110 paise per unit for LT (low tension) connections and 100 paisa/unit for HT (high tension) connections under a metered or pro-rata tariff system (GoO, 2011c). However, the cost of electricity supply has been determined at 408.87 paise per unit for 2011-12 and a subsidy of 298.87 paise per unit is paid by the government. Therefore, an increase in electricity tariff at least by 217 paise per unit is required to reach the lower limit (408.78- 20% =327.07) of the prescribed electricity tariff (± 20% of the supply cost) by the National Electricity Policy (GoO, 2011c). The increase in electricity tariff will not only reduce the subsidy burden on government exchequer but also bring efficiency in the use of groundwater resources due to positive marginal cost of pumping (Saleth, 1997; Kumar and Singh, 2001). But, tariff hike may also curtail the electricity demand and thereby groundwater utilization. Due to the small share of electricity cost in total production cost (Narayanmoorthy, 1997), tariff hike will have a meagre impact on groundwater withdrawal, though there are divergent views on the implications of tariff hike on electricity demand and groundwater use (Saleth, 1997; Kumar and Singh, 2001; de Fraiture and Perry, 2002).

Kumar and Patel (1995) argued that net returns from the well-irrigated commands are more elastic to adequacy and reliability of irrigation water rather than the cost of energy. The positive impact of adequate and quality electricity supply on farm economy will trickle down to well irrigators with 'manual/animal' power who will switch to electric pump to cover higher command area and reduce drudgery. Moreover, the estimated cost of groundwater extraction with the increased electricity tariff rate (327 paise per unit for assessment year 2011-12) was lower (53-133% in the hard rock region and 126-220% in the alluvial region, depending upon type of wells) than of subsidized diesel-operated wells (₹10.94/- per litre as on February,

Table 5. Economics of groundwater extraction in Odisha

Particulars	Hard rock region						Alluvial region					
	Deep tubewells		Filter point wells		Dugwells		Deep tubewells		Shallow tubewells		Dugwells	
	E	D	E	D	E	D	E	D	E	D	E	D
Average horse power of pump (Hp)	7.5	7.5	2.5	2.5	1	1	10	10	3	3	1	1
Water level (m)	6.08	6.08	6.08	6.08	6.08	6.08	4.74	4.74	4.74	4.74	4.74	4.74
Draw –down (m)	20.75	20.75	5	5	2	2	10.99	10.99	5	5	1	1
Total head (m)	29.51	29.51	12.19	12.19	8.89	8.89	17.30	17.30	10.71	10.71	6.31	6.31
GW draft (L/sec)	7.62	7.62	6.15	6.15	3.38	3.38	17.34	17.34	8.40	8.40	4.75	4.75
Diesel(L/m^3)*/electric(kWh/m^3)** consumption	0.204	0.068	0.084	0.028	0.061	0.021	0.120	0.040	0.074	0.025	0.044	0.015
Diesel/electric cost (₹/m^3)	0.22	3.07	0.09	1.27	0.07	0.93	0.13	1.80	0.08	1.12	0.05	0.66
Digging cost ('000 ₹)	300	300	100	100	90	90	150	150	40	40	25	25
Pump cost ('000 ₹)	25	25	15	15	10	10	55	55	15	15	10	10
Annual maintenance cost (₹)	250	1250	150	750	100	500	550	2750	150	750	100	500
Pumping days (No.)												
Monsoon	50	50	50	50	50	50	50	50	50	50	50	50
Non-monsoon	120	120	120	120	120	120	120	120	120	120	120	120
Pumping hours (hours/day)												
Monsoon	5.97	5.9	6.2	6.2	4.12	4.12	4.88	4.88	5.4	5.4	4.23	4.23
Non-monsoon	6.4	6.4	6.95	6.95	4.10	4.10	5.64	5.64	7.33	7.33	4.31	4.31
Annual water extraction (m^3/well)	29271	29271	25343	25343	8482	8482	57474	57474	34765	34765	12464	12464
Annual amortized cost (₹/m^3)	1.18	1.21	0.49	0.52	1.26	1.31	0.37	0.41	0.16	0.18	0.29	0.32
Total irrigation cost (₹/m^3)	1.40	4.29	0.59	1.79	1.33	2.24	0.50	2.21	0.24	1.30	0.34	0.98
Share of energy in total irrigation cost (%)	15.97	71.69	15.82	71.09	5.07	41.38	26.37	81.64	33.27	86.08	14.12	67.00

Notes: E: Electric pump, D: Diesel pump

*1Hp pump consumes about 250 mL diesel per hour

**1Hp=0.746kWh

Data source: GoI (2002b), GoO (2011a; 2011b)

2012). Hence, the farmers with the diesel pumpsets will shift to the electric pumps provided assured and quality electricity supply is guaranteed. Additionally, if conducive product disposal infrastructure (marketing, processing, cold storage, etc) is provided, the assured irrigation will also motivate farmers to diversify towards high-value crops such as vegetables, floriculture, etc. which will accelerate agricultural growth (Srivastava *et al*., 2013). These benefits of the electricity-based irrigation rest on the provision of assured and quality power supply and development of favourable marketing infrastructure in the state. A part of the investment for developing power and marketing infrastructure can accrue by increasing power tariff and reducing estimated annual diesel subsidy of ₹ 5012/- per well. Therefore, in Odisha, which is pioneer in electricity reforms in the country, there is ample opportunity to harness the potential of groundwater resources through suitable energy regulations for accelerated agricultural growth in the state.

Conclusions and Policy Options

The agricultural sector is characterized in Odisha as low input-low return with wide regional inequality. However, in recent years, it has started catching-up with the better performing regions of the country. The sustainable development of groundwater resources, which bears a positive relationship with agricultural income, will accelerate agricultural growth in the state. But, groundwater resources in the state suffer from the dual problems of under-development and under-utilization of the created irrigation potential. The under-development of groundwater is primarily due to the predominance of hardrock geology. Implementation of suitable recharge activities using scientific tools and investigations in these areas would improve the well-yield and therefore, groundwater draft for irrigation. On the other hand, groundwater extraction in the better-developed alluvial/coastal regions needs precautions with respect to sea-water intrusion. The regulation of pumping depth, horse power and pumping hours within the safe limits and its strict monitoring at the local governance level in coastal areas is essential to avoid negative externalities of groundwater development.

The under-utilization of available irrigation potential leads to not only loss of financial resources but also the opportunity to improve agricultural productivity. Non-functioning of wells is one of the important reasons of poor utilization of created potential. These defunct wells maybe repaired, reinstalled and maintained to improve irrigation infrastructure that would involve much less investment than creating new structures in the state. Mass scale non-functionality of deep wells (primarily owned by the government) sets a strong platform for transferring their ownership to better-performing *Pani-Panchayat (*WUA).

The energy-use pattern for groundwater irrigation has exhibited regional variations. In the hard rock region, 'man/animal' power is the dominant energy source, while diesel is the major energy source in the alluvial/coastal region. Poor power infrastructure and unreliable electricity supply are forcing farmers to use diesel-operated pumps over more efficient and technically superior electric pumps. The estimated cost of groundwater extraction at higher electricity tariff after removal of subsidy, is less than that incurred using diesel-operated pumps even at the subsidized diesel price. Therefore, if assured and quality electricity is guaranteed, irrigators with diesel pumpsets as well as 'manual/animal' (in hydro-geologically suitable regions) power will switch to electrical energy to maximize the net profit. Assured irrigation, if accompanied by conducive product disposal infrastructure, will further motivate the farmers to diversify towards high-value crops such as vegetables, floriculture, etc. This will accelerate agricultural growth in the state. However, realization of the above-mentioned benefits rests on the assured and quality electricity supply for irrigation along with conducive market infrastructure. A part of the investment needed for creating such infrastructure can be met by the removal of electric as well diesel subsidy. Therefore, there is ample opportunity to harness the potential of groundwater resources through suitable technological interventions and energy regulations for accelerated agricultural growth in the state of Odisha.

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